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(54) Optical system for light beam scanning.

(57) A scanning optical system used for light beam scanning device is disclosed. The scanning optical system is disposed between a deflector for deflecting a light beam and a plane to be scanned. In the scanning optical system, a spherical lens having a positive power and a toric lens are arranged. The toric lens is positioned close to the spherical lens at the side thereof closer to the plane to be scanned. The toric lens has positive powers both in the main and sub scanning cross sectional planes. At least one of the faces of the toric lens is aspherical in the main scanning cross sectional plane.

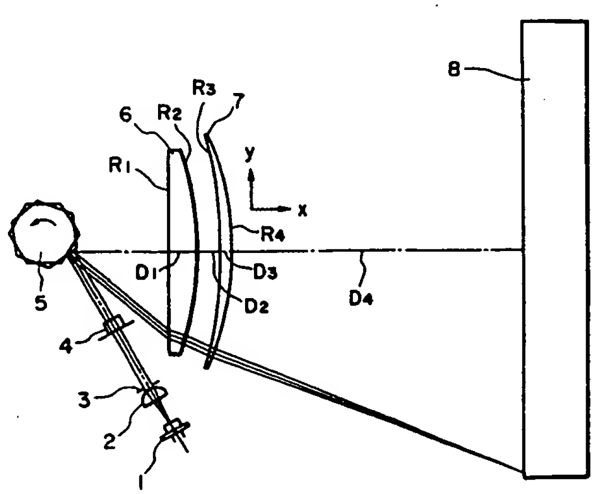

FIG. 1

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OPTICAL SYSTEM FOR LIGHT BEAM SCANNING

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an optical system for light beam scanning, adapted for use in a laser beam printer, a digital copying machine or the like.

Related Background Art

Conventional optical systems for such light beam scanning generally utilize light beam deflection by a rotary polygon mirror, as disclosed in the U.S. Patent No. 4,379,612. If the reflecting faces of such polygon mirror involve an angular error (face inclination) with respect to the rotary axis, the light beam in scanning motion is displaced to undesirably influence the final image output. In order to avoid such undesirable influence of the face inclination, there is already proposed, as described in the above-mentioned patent, to place the rotary polygon mirror and the scanned plane (irradiated plane) in a optically conjugate relationship by means of a toric lens. It is also proposed, as described in the U.S. Patent No. 4,639,072, to alleviate the influence of the face inclination by positioning a cylindrical lens in the vicinity of the plane scanned by the light beam.

However, in the above-mentioned structure employing a toric lens, in order to correct the aberrations for maintaining desired optical performance, the toric lens has to be close to a plano-convex lens in the shape in the main scanning cross-sectional plane, and a spherical concave lens positioned between the toric lens and the rotary polygon mirror has to be close to a plano-concave or biconcave shape, so that the image angle is inevitably limited. Stated differently, a wider image angle with same optical performance will inevitably require thicker lenses, and as a result, the apparatus will become large.

Also it is generally difficult to manufacture the toric lens, and the use of the toric lens, is a factor of increased cost.

In order to avoid such drawbacks, there can be conceived to prepare the toric lens with a plastic material, but, since said toric lens represents a significant portion in the power of the entire conventional optical system consisting of a concave spherical lens and a convex toric lens from the side of the rotary polygon mirror, the power fluctuation in the plastic lens resulting from changes in ambient conditions is not negligible and results for example in a defocus on the scanned plane.

On the other hand, the other conventional structure utilizing the cylindrical lens in the vicinity of the scanned plane is less affected by the ambient conditions, but the presence of such optical component as the cylindrical lens close to a photosensitive drum is undesirable, for example in an electrophotographic laser beam printer, because various process components such as the developing unit and the cleaning station are positioned close to the photosensitive drum. Also such cylindrical lens, if positioned close to the photosensitive drum, is apt to be subjected to undesirable influence by stain with toner, heat, ozone etc.

SUMMARY OF THE INVENTION

In consideration of the foregoing, the object of the present invention is to provide an optical system for light beam scanning, excellent in performance, widening of image angle, compactization, resistance to fluctuation in ambient conditions, and cost.

The above-mentioned object can be attained, according to the present invention, by a scanning optical system, for use in a light beam scanning device for deflecting a light beam by deflection means (for example a rotary polygon mirror) thereby scanning a plane (for example a photosensitive drum) and to be positioned between said deflection means and said scanned plane, said optical system being composed of a spherical lens with a positive power and a toric lens positioned close to a face of said spherical lens, facing said scanned plane, and having positive powers both in the main and sub scanning cross sections, wherein at least a face of said toric lens in the main scanning cross section is aspherical.

More specifically, said spherical lens is approximately planar in a face thereof closer to the deflection means, and is convex in the other face closer to the scanned plane. The toric lens has a concentric shape, having the center of radius of curvature at a side closer to th deflection means. In addition said toric lens is so designed to satisfy at least one of following relations:

$0.1 < f_a/f_{2a} < 0.3$
$0.25 < f_{2b}/f_a < 0.5$
$0.6 < \ell/f_a < 1$
$0 < d_{max}/f_{2b} < 0.15$

wherein f_{2a} is the focal length of the toric lens in the main scanning cross section; f_{2b} is the focal length of the toric lens in the sub scanning cross section; f_a is the synthesized focal length of the spherical lens and the toric lens in the main scanning cross section; ℓ is the distance between the toric lens and the scanned plane; and d_{max} is the maximum thickness of the toric lens in the optical axis.

The toric lens may be composed for example of a plastic material, and, among the four conditions mentioned above, the latter two are important in forming the toric lens with a plastic material.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view of a first embodiment of the present invention in the main scanning plane thereof;
Fig. 2 is a view of the first embodiment of the present invention in the sub scanning plane thereof;
Fig. 3 is an aberration chart of the image plane curvature of the first embodiment;
Fig. 4 is an aberration chart showing the f-θ characteristics of the first embodiment;
Fig. 5 is a view of a second embodiment; and
Fig. 6 is a view of a third embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now the present invention will be clarified in detail by preferred embodiments thereof shown in the attached drawings.

Figs. 1 and 2 illustrate a first embodiment of the present invention, respectively in the main scanning cross-sectional plane and in the sub scanning cross-sectional plane including the optical axis and perpendicular to the main scanning plane.

Referring to Fig. 1, a light beam emitted by a semiconductor laser 1 is converted into a substantially parallel beam by a collimating lens 2, then is shaped in the size of cross-section by a diaphragm aperture 3 and enters a cylindrical lens 4. As said cylindrical lens 4 has a power in the sub scanning cross section but is powerless in the main scanning cross section, the light beam enters a rotary polygon mirror 5 maintaining the parallel beam state in the main scanning cross section but being focused in a line in the sub scanning cross section. The rotary polygon mirror 5 is rotated at a constant high speed in a direction indicated by an arrow, so that the incident light beam is deflected by reflection by said mirror and put into a scanning motion in the main scanning plane.

The light beam deflected with a constant angular velocity passes through a spherical lens 6 of a positive power and a toric lens 7 having positive powers both in the main and sub scanning cross sections, and is focused on a photosensitive drum 8, achieving a linear scanning motion with a substantially constant speed.

Referring to Fig. 2, P indicates the position of reflecting face of the rotary polygon mirror 5, and, in the sub scanning cross section, the light beam substantially converges on this point P as explained above. Since the reflecting face P and the photosensitive drum 8 are optically substantially conjugate, the light beam can be focused on the same scanning line on the photosensitive drum 8 even if the reflecting face P involves an angular error (face inclination) in the sub scanning cross sectional plane. Thus provided is a compensating system for the face inclination of the rotary polygon mirror 5.

In the above-explained structure, the scanning lenses 6, 7 are constructed in the following manner, for realizing satisfactory image plane curvature and f-θ characteristics over a wide image angle in the main scanning plane.

At first, in the spherical lens 6 of positive power, the face positioned closer to the rotary polygon mirror 5 is formed almost planar, in order to generate a negative distortion for realizing satisfactory f-θ characteristics. The face positioned closer to the photosensitive drum is formed convex thereto, in order to satisfactorily correct the image plane curvature.

The toric lens 7 is positioned behind and close to the spherical lens 6, and has a concentric shape (centers of radii of curvature of both faces of said toric lens 7 being positioned at the side of the rotary polygon mirror and mutually close) in which at least one of the faces is aspherical in the main scanning cross sectional plane, in order to correct the curvature of image plane over a wide image angle. Besides, since well-balanced corrections of the f-θ characteristics and the image plane curvature in the scanning direction or in the meridional direction become difficult in case of an excessive power of the toric lens 7 in the main-scanning cross sectional plane, said power is preferably so reduced as to satisfy a condition 0.1 <

$f_a/f_{2a} < 0.3$, wherein f_{2a} is the focal length of the toric lens in the main scanning cross sectional plane while f_a is the synthesized focal length of the spherical lens 6 and the toric lens 7 in said plane.

More specifically, if below the lower limit (i.e. $f_{2a} > 10\ f_a$), the correction of aberrations is made easier but the toric lens 7 is positioned closer to the scanned plane (photosensitive drum 8) and becomes inevitably large. On the other hand, if above the upper limit (i.e. $f_{2a} < 3.333..\ x\ f_a$), a smaller value of f_{2a} is favorable for compactization of the apparatus but renders it difficult to correct the f-θ characteristics and the image plane curvature in well balanced manner.

On the other hand, the focal length f_{2b} of the toric lens 7 in the sub scanning cross sectional plane is preferably so selected as to satisfy a condition $0.25 < f_{2b}/f_a < 0.5$ in order to satisfactorily correct the image plane curvature in the sagittal direction (perpendicular direction to the optical axis in the sub scanning cross sectional plane).

Above the upper limit of said condition (i.e. $f_{2b} > 0.5f_a$), f_{2b} becomes larger, thus facilitating the correction of aberrations but the toric lens 7 is undesirably positioned closer to the scanned plane (photosensitive drum 8) as in the aforementioned conventional structure. Also below the lower limit (i.e. $f_{2b} < 0.25f_a$), f_{2b} becomes smaller, rendering it difficult to achieve balanced corrections of the image plane curvature in the meridional and sagittal directions.

Furthermore, the toric lens 7 is preferably so positioned as to satisfy a relation $0.6 < \ell/f_a < 1$ wherein ℓ is the distance between the toric lens 7 and the scanned plane. Below the lower limit (i.e. $\ell < 0.6f_a$), the apparatus becomes bulky and the effect for compensating the face inclination becomes limited. On the other hand, above the upper limit (i.e. $\ell < f_a$), the toric lens 7 will have a stronger power, and there will result an untolerable defocus on the scanned plane, for example due to changes in the ambient conditions, particularly when the toric lens 7 is formed by a plastic material in consideration of the cost.

Furthermore, the toric lens 7 is preferably formed so thin as to satisfy a condition $0 < d_{max}/f_{2b} < 0.15$, wherein d_{max} is the maximum axial thickness of the toric lens. This condition reduces the defocus on the scanned plane, resulting from changes in ambient conditions, particularly moisture absorption of the toric lens 7, and facilitates the molding thereof with a plastic material.

As explained in the foregoing, the use of a thin toric lens of a relatively weak power, including an aspherical face, allows to obtain an inexpensive scanning optical system showing satisfactory performance over a wide image angle and little affected by changes in the ambient conditions even when the toric lens is molded with a plastic material.

Figs. 3 and 4 show the image plane curvature and the f-θ characteristics of the first embodiment, in which the spherical lens with positive power is composed of glass while the toric lens of positive power is composed of a plastic material.

In the following there is given a specific numerical example of the first embodiment:

Focal length of entire system	184 mm
Maximum scanning angle	80°
Deflection point - R_1 plane	54.6 mm
$R_1 = \infty$	$D_1 = 16.7$

$$N_1 = 1.78569$$

$$R_2 = -181.29 \qquad D_2 = 12.1$$

$$R_3 = -575.78 \qquad D_3 = 6.8$$

$$N_3 = 1.51920$$

$$B = -4.06691 \times 10^{-7}$$

$$C = 4.54821 \times 10^{-11}$$

$$D = -9.52776 \times 10^{-16}$$

$$R_3' = -22.26$$

$$R_4 = -247.28 \qquad D_4 = 170.8$$

$$B = -3.45955 \times 10^{-7}$$

$$C = 3.00766 \times 10^{-11}$$

$$D = 5.63771 \times 10^{-16}$$

$$R_4' = -15.10$$

wherein R_1 - R_4 are radii of curvature of the lens faces in the main scanning cross sectional plane, in the order from the side of rotary polygon mirror 5 as shown in Figs. 1 and 2; R_3' and R_4' are radii of curvature in the sub scanning cross sectional plane; D_1 - D_4 are distances between lens faces; N_1 and N_2 are refractive indexes at 780 nm of the lenses in the order from the side of the rotary polygon mirror 5; and B - D are aspherical coefficients in the following relation between the height y and distance x of the lens face on the x-y plane:

$$x = y^2/R[1 + \{1 - (y/R)^2\}^{\frac{1}{2}}] + By^4 + Cy^6 + Dy^8$$

Fig. 5 shows a second embodiment of the scanning optical system in the main scanning cross sectional plane, of which numerical example is given in the following. The spherical lens of positive power is composed of glass, while the toric lens of positive power is composed of a plastic material.

The aspherical face of the toric lens 17, positioned closer to the spherical lens 16, is formed almost planar in a portion close to the optical axis. The symbols are defined same as in the foregoing numerical example.

Focal length of entire system	184 mm
Maximum scanning angle	80°
Deflection point - R_1 plane	51 mm

$R_1 = \infty$	$D_1 = 17.7$
	$N_1 = 1.78569$
$R_2 = -193.95$	$D_2 = 8.0$
$R_3 = -1479.75$	$D_3 = 6.9$
	$N_3 = 1.51920$
$B = -4.35513 \times 10^{-7}$	
$C = 2.88834 \times 10^{-11}$	
$D = -1.51643 \times 10^{-15}$	
$R_3' = -23.00$	
$R_4 = -286.29$	$D_4 = 174.4$
$B = -3.59684 \times 10^{-7}$	
$C = 1.25611 \times 10^{-11}$	
$D = -6.52037 \times 10^{-16}$	
$R_4' = -14.95$	

Fig. 6 shows a third embodiment of the scanning optical system in the main scanning cross sectional plane, of which numerical example is given in the following. The spherical lens of positive power is composed of glass, while the toric lens of positive power is composed of a plastic material. In said third embodiment, the toric lens 27 is aspherical only in one face (positioned closer to the spherical lens 26) thereof.

Focal length of entire system	184 mm
Maximum scanning angle	80°
Deflection point - R_1 plane	60.1 mm

$R_1 = \infty$	$D_1 = 20.1$
	$N_1 = 1.78569$
$R_2 = -160.70$	$D_2 = 35.1$
$R_3 = 3576.64$	$D_3 = 7.8$
	$N_3 = 1.48595$
$B = -2.48657 \times 10^{-7}$	
$C = 3.10118 \times 10^{-13}$	
$D = 0$	
$R_3' = -18.96$	
$R_4 = -900.03$	$D_4 = 146.6$
$B = 0$	
$C = 0$	
$D = 0$	
$R_4' = -14.11$	

As explained in the foregoing, a scanning optical system, for use in a light beam scanning device for deflecting a light beam by deflection means thereby scanning a plane and to be positioned between said deflection means and said scanned plane, is constructed according to the present invention by a spherical lens of a positive power and a toric lens positioned close to said spherical lens at a side thereof closer to the scanned plane and having positive powers both in the main and sub scanning cross sectional planes, wherein at least a face of said toric lens is formed aspherical, thereby achieving high optical performance while compensating the eventual face inclination error in the rotary polygon mirror. Also the scanning optical system can be obtained inexpensively by forming the toric lens with a plastic material.

A scanning optical system used for light beam scanning device is disclosed. The scanning optical system is disposed between a deflector for deflecting a light beam and a plane to be scanned. In the scanning optical system, a spherical lens having a positive power and a toric lens are arranged. The toric lens is positioned close to the spherical lens at the side thereof closer to the plane to be scanned. The toric lens has positive powers both in the main and sub scanning cross sectional planes. At least one of the faces of the toric lens is aspherical in the main scanning cross sectional plane.

Claims

1. A scanning optical system, for use in a light beam scanning device for deflecting a light beam by deflection means thereby scanning a plane and to be positioned between said deflection means and said scanned plane, comprising:
   a spherical lens with a positive power; and
   a toric lens positioned close to said spherical lens at the side thereof closer to the scanned plane

and having positive powers both in the main and sub scanning cross sectional planes, wherein at least one of the faces of said toric lens is aspherical in the main scanning cross sectional plane.

2. An optical system according to claim 1, wherein said spherical lens is approximately planar in a face thereof closer to the deflection means, and is convex to the scanned plane in a face thereof closer to said scanned plane.

3. An optical system according to claim 1, wherein said toric lens has a concentric shape with centers of radii of curvature at the side thereof close to the deflection means.

4. An optical system according to claim 1 further satisfying a relation:

$0.1 < f_a/f_{2a} < 0.3$

wherein f_{2a} is the focal length of said toric lens in the main scanning cross sectional plane, and f_a is the synthesized focal length of said spherical and toric lenses in said plane.

5. An optical system according to claim 1 further satisfying a relation:

$0.25 < f_{2b}/f_a < 0.5$

wherein f_{2b} is the focal length of said toric lens in the sub scanning cross sectional plane, and f_a is the synthesized focal length of said spherical and toric lenses in the main scanning cross sectional plane.

6. An optical system according to claim 1 further satisfying a relation:

$0.6 < \ell/f_a < 1$

wherein f_a is the synthesized focal length of said spherical and toric lenses in the main scanning cross sectional plane, and ℓ is the distance between said toric lens and said scanned plane.

7. An optical system according to claim 1 further satisfying a relation:

$0 < d_{max}/f_{2b} < 0.15$

wherein f_{2b} is the focal length of said toric lens in the sub scanning cross sectional plane, and d_{max} is the maximum thickness of said toric lens in a direction of the optical axis.

8. An optical system according to claim 1, wherein said toric lens is composed of a plastic material.

9. A scanning optical system, for use in a light beam scanning device for deflecting a light beam by deflection means thereby scanning a plane and to be positioned between said deflection means and said scanned plane, comprising:
a first lens of a positive power composed of glass; and
a second lens of a positive power composed of a plastic material, positioned close to said first lens at a side thereof closer to said scanned plane.

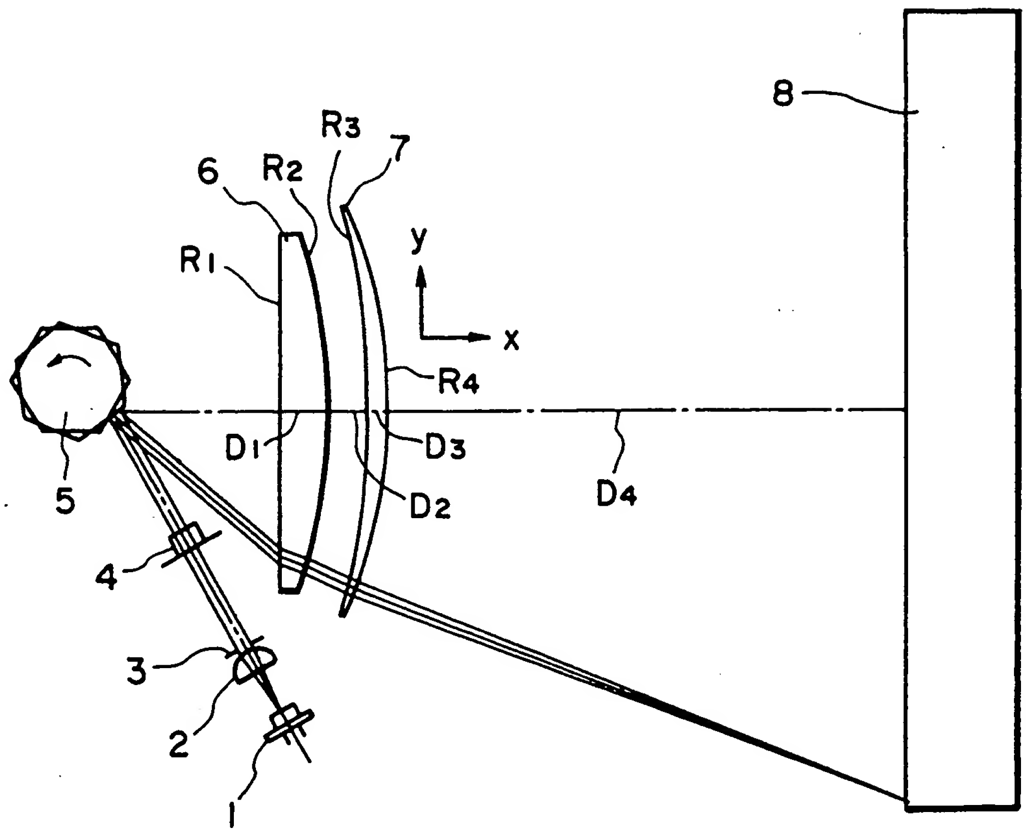

FIG. 1

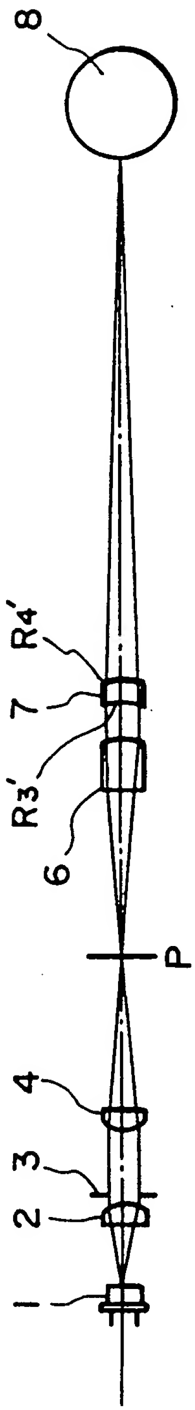

FIG. 2

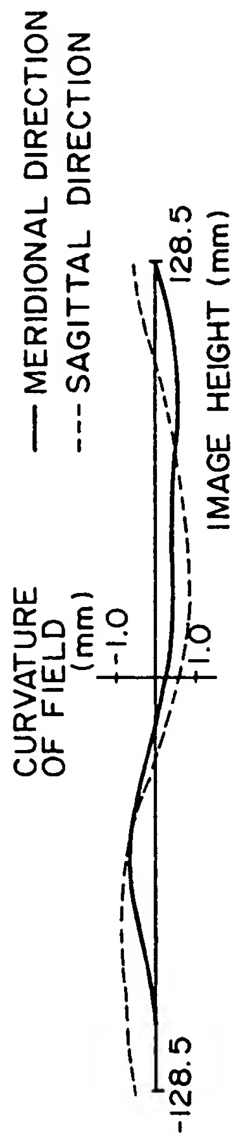

FIG. 3

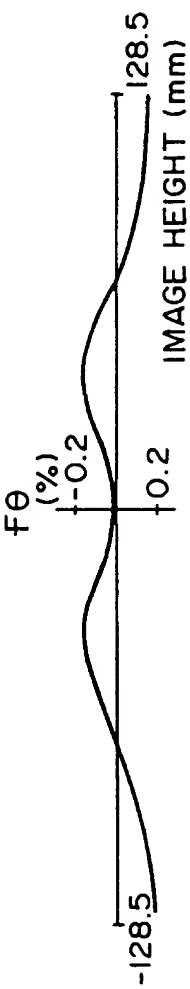

FIG. 4

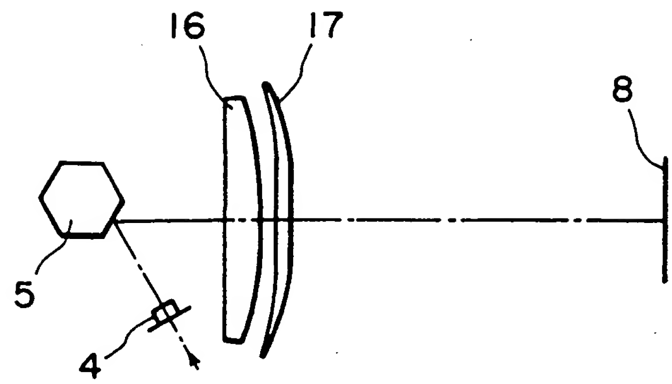

FIG. 5

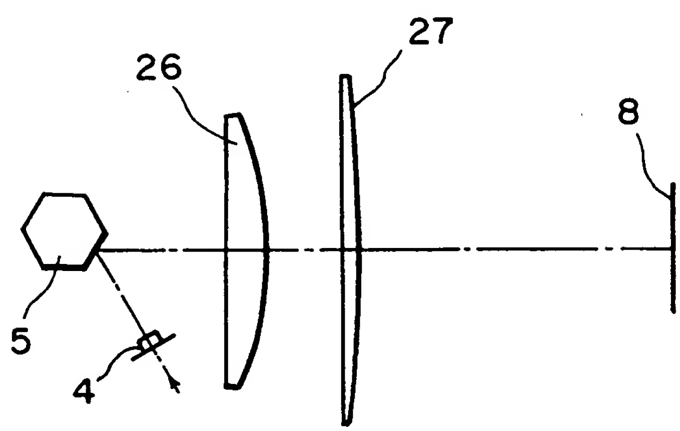

FIG. 6